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R&D Internationalization Strategies of the World's Top Corporate R&D Investors

Heike Belitz[1] and Anna Lejpras[2*]

[1]German Institute for Economic Research Berlin (Deutsches Institute für Wirtschaftsforschung Berlin), Mohrenstrasse 58, 10117 Berlin Germany; Email: hbelitz@diw.de

[2]BSP Business and Law School, Calandrellistrasse 1-9, 12347 Berlin Germany

*Correspondence: anna.lejpras@businessschool-berlin.de

Abstract

This paper examines how multinational enterprises (MNEs) internationalize their R&D activities. We address three questions: (1) What determines the level of R&D internationalization? (2) What strategies dominate home-base-augmenting (HBA), home-base-exploiting (HBE), technology-seeking (TS), or market-seeking (MS)? And (3) What are the patterns in strategy mixes? We merge data on 2,000 global research leaders (2012–2014) with the EPO PATSTAT database, covering roughly 1,700 top corporate R&D investors and their patenting. We find that about one-fifth of these investors concentrate their patent-relevant R&D domestically. Our results indicate that leading R&D performers use offshoring primarily to acquire complementary technological knowledge (HBA) and to leverage home-based technological strengths for market expansion (HBE). The increasing proportion of HBA strategies in the late 2010s highlights the growing importance of international knowledge exchange, suggesting that the rise of foreign R&D locations does not undermine national innovation systems.

Keywords: R&D, Patents, Innovation, Internationalization, Multinational Firms, Global Firms

JEL Classification: F23, O19, O31, O32

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1. Introduction

Multinational companies develop their products and processes not only at home but also in foreign markets, adapting them to local conditions and customer requirements. Setting up company research laboratories abroad can also serve the purpose of studying the new technological knowledge of local competitors, universities, and research institutes, or developing new products and processes in a specialized local R&D environment. Acquiring the know-how of research personnel in the host country is a further key motive for R&D abroad (Oecd, 2008). The R&D activity of multinationals overseas is sometimes characterized as "relocation of R&D." Foreign R&D operations may substitute for domestic ones, thereby, reducing the growth potential of the economy. It is suggested that the internationalization of R&D by domestic firms might result in a "hollowing out" of domestic capabilities, as firms decrease domestic R&D activities while increasing foreign activities. This is regarded as indicative of a weakening domestic competitiveness of the home location. A counterargument for this "hollowing out" argument is provided by empirical studies showing that the stronger the overall R&D base in a certain home country is, the more likely the firms in that country outsource their R&D (Alkemade in drugi, 2015).

Not only informed innovation and R&D policies but also R&D management of MNEs critically depend on a precise overview of the scope and direction of R&D of multinational enterprises as well as insights into the relevance of national, sectoral, technological and company-related drivers of R&D internationalization—both are currently lacking (Alkemade in drugi, 2015; D'agostino in Santangelo, 2012). The technological and regional distribution of the R&D activities of multinational companies at home and abroad provides an indication of the motives for their internationalization. Was it driven by the desire to acquire new technological knowledge or by customer requirements and conditions in the target market? Are the companies enhancing their knowledge abroad in the technologies in that they have a domestic advantage in their research laboratories? Or are they involved with technologies they need to catch up on and, as a result, must carry out research at foreign locations? This paper aims to shed some more light on these issues. We study the extent and technological orientation of the R&D activities of multinational companies at home and abroad between 2012 and 2014. To this end, we merge patent data from the European Patent Office with firm data on the 2000 top corporate R&D performers worldwide. Due to missing data, the final dataset contains information on the patenting activities of about 1,700 companies. Patent information can be used to examine which strategies the companies pursue in certain technology fields through their R&D activities abroad. Patent data allows for determining whether or not the top R&D corporate leaders carry out research in technologies in which the host countries have technological advantages: in a global comparison, those in which they are highly specialized. On the one hand, this would indicate that, in these countries, companies are primarily searching for technological knowledge that is not available to them at home. On the other hand, if they conduct research in technological fields in which the host countries are not

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specialized (that is, in which they do not have a distinct knowledge base), we can conclude that they are driven by market-related motives.

To characterize the R&D internationalization strategy of companies by technology and host country, we use the same classification scheme of Patel in Vega (1999), which is applied in the literature (see, e.g., Laurens, Le Bas, Schoen, Villard, in drugi, 2015; Le Bas in Sierra, 2002). Previous studies yield insights into the dominance and an increasing trend toward asset-augmenting activities in different firm samples until 2005. However, since most firms tend to employ various internationalization strategies in different technologies simultaneously, we examine different strategy mixes in multinational companies. To the best of our knowledge, we are the first to do so. Thus, the main aim of the paper is to investigate the R&D offshoring of those multinational firms investing the largest sums in R&D worldwide. We contribute to the literature on offshoring motives and address the following questions: How do these companies differ in the extent and the strategies of R&D abroad? Are there typical patterns of their internationalization strategies in groups of firms? What are the drivers of these strategy-mixes? Do the home country of the firm, the sector, the technologies, and their diversity influence the extent of R&D offshoring and the combination of internationalization strategies pursued?

To answer these questions, we perform our analysis in three steps. First, we explore the relationship between the R&D internationalization level of top global R&D investors and various company-specific characteristics as well as features related to their R&D activities, using the fractional response estimation approach. Second, based on the approach of Patel in Vega (1999), we determine the R&D strategies employed by the global research leaders for each technological field in their R&D operations. To account for the fact that companies pursue different R&D internationalization strategies in various technological fields, we use the k-means clustering method to identify typical patterns in pursuing R&D internationalization strategies by the world's top research performers. In the third step, we estimate a multinomial logit model to investigate the technology-related determinants and company-specific attributes behind the choice of strategy mixes identified using the clustering approach. The paper proceeds as follows: First, in Section 2, we describe the widely used concept of four internationalization strategies and prior work to identify the extent these strategic options are used by multinational companies. Section 3 gives details on the dataset, and the methodology used in this paper. Section 4 provides the results of our analysis and Section 5 discusses them. Finally, the article concludes with policy implications and limitations of our study (see Section 6).

2. R&D Offshoring – Motives and Strategies

R&D in multinational enterprises (MNE) is moving from centralized and geographically confined toward distributed and open structures. Still, maintaining a well-balanced locally responsive and globally efficient R&D network is one of the great challenges of multinational organizations (Gassmann in drugi, 2018). In this section, we first summarize the literature on motives and

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strategies for MNEs' overseas R&D activities. We then present an overview of empirical studies on the extent and the determinants of internationalization strategies of MNEs. Finally, we derive research questions, which we intend to answer based on the data of world's top corporate R&D investors and their patenting activity.

2.1 Two Main Drivers of R&D Internationalization

International R&D activities have always exhibited a high heterogeneity across countries, industries and, even more so, across firms—and this is true both in quantitative and qualitative terms (Papanastassiou in drugi, 2020). Scholars in the 1990s—e.g., Dunning in Narula (1995), Kuemmerle (1999), Patel in Vega (1999), (Sambharya in Lee, 2014) and Veliyath in Sambharya (2011)—find two main drivers of R&D internationalization: firms either adapt their products to local markets and, thus, further exploit their technological home base (home-base-exploiting or asset-exploiting strategy, HBE) or look for complementary technologies and, hence, augment the firm capabilities abroad (home-base-augmenting or asset-augmenting strategy, HBA). It is often assumed that firms first internationalize their R&D because of the need to improve the way in which existing assets are utilized (Criscuolo in drugi, 2002). In this home-based exploiting mode (HBE), firms may seek to promote the use of their technological assets in conjunction with, or in response to, specific locational conditions in a foreign locale. Locational conditions may require some level of modification to the product and/or processes to make them more appropriate to local conditions. The second broad classification is that of home-base augmenting (HBA) activity. In this type of investment, through their foreign-located R&D facilities either firms aim to improve their existing assets or firms aim to acquire or create completely new technological assets. The assumption in such cases is that the foreign location provides access to location-specific advantages that are not as easily available in the home base. The investing firm may seek to enable access to the technological assets of other firms, either through spillovers via direct acquisition (via M&A), or through R&D alliances. HBA activities are primarily undertaken with the intention to acquire and internalize technological spillovers that are specific to the host-location. In contrast, the above mentioned HBE activities are primarily associated with demand-based activities.

In the literature, we find a dispute over whether R&D laboratories abroad follow a clear strategy. Zander (1999) argues that any given facility performs both HBE and HBA, because products and processes require multiple technological competences. Any given subsidiary has a need for a variety of technologies, while any given host location may possess a relative technological advantage in one area but be relatively disadvantaged in another. Criscuolo in drugi (2005) argue that most firms tend to undertake both HBE and HBA activities simultaneously. However, looking at the individual laboratories, other researchers observe R&D laboratories following a clear mission. R&D units focus either on the exploitation of corporate capabilities or the augmentation of the firms' capabilities. Only a few units have a joint focus on capability augmenting and capability exploiting tasks (Ambos, 2005; Kuemmerle, 1999).

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2.2 National, Sectoral and Technological Patterns of Internationalization

At the turn of the century, empirical studies concluded that there was an increasing internationalization movement; however, scholars underlined the rather limited levels of internationalization (Le Bas in Sierra, 2002; Patel in Vega, 1999; Unctad, 2005).[1] Alkemade in drugi (2015) show a significant heterogeneity in sectoral and national patterns of internationalization. These patterns have remained relatively stable over the period from 1993 to 2005. The main effect for outward R&D is that the stronger the overall R&D base in a specific country measured by the number of patents applied for by the MNEs, the more likely the firms in that country are to outsource their R&D. No significant sector-related effects were found. In accordance with the idea that the smaller the country, the more internationalized its firms are, Laurens, Le Bas, Schoen in Larédo (2015) find high internationalization rates for firms headquartered in the smallest countries (Netherlands, Switzerland, Sweden). These results are in line with those shown by Patel in Vega (1999) and Le Bas in Sierra (2002). Other research suggests that, compared to large countries, smaller countries are dependent on collaboration activities to a greater extent to compensate for the lack of home capabilities (Danguy, 2017). In their OLS estimates of the annual rate of R&D internationalization, Laurens, Le Bas, Schoen in Larédo (2015) find significant effects of the dummy variables for countries—thus indicating that the home base significantly affects the degree of R&D internationalization. Regarding the differences between industrial sectors, Gammeltoft (2006) concludes, based on a literature review, that firms in industries with higher technological complexity tend to retain their technological activities in their country of origin. Yet, companies engaged in traditional sectors are those with the most innovative activities outside the home base. Other scholars present evidence on the concentration of R&D internationalization in high-technology sectors, such as pharmaceuticals, computers, electronics, machinery, and the automotive industry (Dachs, 2017; Moncada-Paternò-Castello in drugi, 2011). Another factor influencing the R&D internationalization is the increasing complexity of products. This forces MNEs to rely upon an expanding number of specialized fields of knowledge. Therefore, firms must master innovations across a wide range of technology fields, with this often requiring the location of R&D facilities in centers of excellence around the world (Moncada-Paternò-Castello in drugi, 2011).

2.3 R&D Internationalization Strategies

An early study by Patel in Pavitt (1991) finds that the sectoral specialization of national large firms in foreign countries often reflects those of parent firms, with the strong exceptions of France and the USA. Other studies show that MNEs source those technologies from abroad for which they do not enjoy a comparative advantage. Cantwell (1999) finds that American multinational

[1] For example, in the study of Thomson, R. (2013). National scientific capacity and R&D offshoring. *Research Policy*, *42*(2), 517-528. on OECD member countries, the share of patents assigned to foreign firms rose from 4.3 to 11.1 percent over the period 1985–2005.

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corporations in the United Kingdom moved away from their historical focus on the industries in which they were strongest at home, toward industries in which indigenous British companies have the greatest technological expertise. In an analysis of the largest leading European firms over the 1969 to 1995 period, Cantwell in Janne (1999) find evidence supporting the hypothesis that leading multinational firms tend to carry out technological activity abroad that is relatively differentiated from their domestic technological strengths. Constructing an industry-country patent data set covering 1980 to 2005, Danguy (2017) shows that countries tend to be more globalized in industrial sectors in which they are less technologically specialized. It suggests that the globalization of innovation is a means of acquiring technological knowledge sources abroad that are lacking in the home region.

Patel in Vega (1999) suggest a framework to analyze internationalization strategies of multinational companies based on the comparative technological advantage of the firm at home and host countries:

- In the *Home-Base-Exploiting* (HBE) internationalization strategy, firms use their national comparative technological advantage to adapt their core technology in host countries not specialized in that technology. A firm possessing a competitive advantage in a technology field in its home market seeks to exploit it abroad, particularly in regions that are weak in the technology field considered.
- *Home-Base-Augmenting* (HBA) or 'strategic asset-seeking' R&D strategy (Dunning in Narula, 1995) consists of targeting technologies in which the company has a relative technological advantage at home and in which the host country is also relatively specialized. The search for complementary assets (knowledge sourcing approach) characterizes this type of conduct.
- With a *Technology-Seeking* (TS) strategy, a firm compensates its national under-specialization in a given technology by seeking foreign skills in host countries specialized in the same technology.
- *Market-Seeking* strategy (MS) corresponds to situations where a firm invests abroad in technological activities in which it is relatively weak in its home country, and the host country is also relatively weak. The motivation for this fourth type of strategy seems not to be technology oriented. Consequently, the authors regard this internationalization strategy as driven by market considerations.

Each locational strategy can be characterized by a binomial relation between the firm Revealed Technological Advantage (RTA) indexes in its home country and the RTA of the country in which it invests a part of its R&D activity (Le Bas in Sierra, 2002; Patel in Vega, 1999) (see Table 1).

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Table 1. Four Locational Strategies for FDI in R&D

		Technological activities in the host country	
		strong	**weak**
Corporate technological activities in the home country	strong	(1) home-base augmenting (HBA) $HomeRTA > 1$ $HostRTA > 1$	(2) home-base exploiting (HBE) $HomeRTA > 1$ $HostRTA < 1$
	weak	(3) technology-seeking (TS) $HomeRTA < 1$ $HostRTA > 1$	(4) market-seeking (MS) $HomeRTA < 1$ $HostRTA < 1$

Source: Le Bas in Sierra (2002) and Patel in Vega (1999).

A stream of empirical studies of large firm samples using patent data provides evidence that home-based technological advantages of the firm are the starting point for their offshoring activities (Laurens, Le Bas, Schoen in Larédo, 2015; Le Bas in Sierra, 2002; Patel in Vega, 1999). The results emphasize the continuing reliance of firms on the home country as a base for innovation. These authors highlight that R&D offshoring does not aim at offsetting home technological knowledge weaknesses, but at augmenting or exploiting a strong home technological potential. In a large majority of cases, companies tend to locate their technology abroad in their core areas where they are strong at home. Only in a small minority of cases, enterprises go abroad in their areas of weakness at home to exploit the technological advantage of the host country (Patel in Vega, 1999).

Overall, the search for complementary assets (HBA) is dominant in studies for different samples of firms and different periods (Laurens, Le Bas, Schoen, Villard, in drugi, 2015; Le Bas in Sierra, 2002; Patel in Vega, 1999). In the period from 2003 to 2005, HBA and HBE strategies accounted for 42 and 39 percent, respectively. Both TS and MS strategies play a much smaller role—the share of each amounted to less than 10 percent in that period (Table A 1). It is often assumed that the HBE strategy is the starting point of the R&D internationalization of a firm. Until the 1980s, the main reason was to exploit firm-specific capabilities while adapting products and processes to foreign contexts. Since the 1990s, strategic asset-seeking is an increasingly common behavior among MNEs (Amighini in drugi, 2013). Using a survey of US subsidiaries in the United Kingdom for the 1969 to 1995 period Cantwell in drugi (2004) argue that the local innovation of MNEs is moving closer to the industries of host country technological advantage and, hence, to utilizing location-specific capabilities as a source of competitive advantage in the MNE. The authors interpret this finding as a shift from an asset-exploiting toward an asset-augmenting form of foreign direct investment. Sachwald (2008) and Moncada-Paternò-Castello in drugi (2011) observe an increasing trend toward asset-augmenting activities in the two decades after 1990. However, asset-exploiting motivations remain important. Therefore, both motives coexist.

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Laurens, Le Bas, Schoen in Larédo (2015) using a patent dataset of a sample of 349 firms and two time periods from 1994 to 1996 and from 2003 to 2005 to show that HBA and HBE remain the dominant behaviors in Europe, which is in line with previous studies (Patel in Vega, 1999).

The dominant share of HBA strategies fits with the observation that key knowledge-generating territories around the world are usually not just home to multinational firms that construct and participate in global innovation networks, but they are also very likely to host foreign firms that wish to gain access to their knowledge-generating ecosystems, talent pool, and researchers (Crescenzi in drugi, 2020). In the study by Laurens, Le Bas, Schoen, Villard, in drugi (2015), the search for complementary assets (HBA) diminishes slightly between the mid-1990s and the mid-2000s while the exploitation of home technologies abroad (HBE) rises slowly (Table A 1 in the Appendix). Both TS and MS strategies remain stable over the two periods of time. Picci in Savorelli (2012) also highlight the fact that the relevance of home-base augmenting motivations for internationalization has not increased. These two studies contrast with the conclusions derived from the literature review, which anticipates a continued growth of home-base-augmenting motivation. In a 2020 literature review, Papanastassiou in drugi (2020) stress that there is no evidence that more traditional asset-exploiting strategies have disappeared. Instead, there is rather convincing, evidence that different R&D strategies coexist and are likely to continue to do so. Some scholars point toward sector specifics regarding the choice of internationalization strategy, suggesting that asset-exploiting is one of the most widely implemented strategies in electronics and metals, while asset-augmenting is more prominent among chemicals, pharmaceuticals, mining, food, and materials (Patel in Vega, 1999).

Using logit models, Le Bas in Patel (2007) identify factors increasing the probability of choosing the home-base-augmenting strategy. These are the volume of technological activity (although this effect is very weak), the degree of technological specialization (the opposite of technological diversification), and the nationality of the firm. The estimates show that there is no significant effect of the current level of technological internationalization (Le Bas in Patel, 2007). Schubert in drugi (2016) show for German firms with low technological capabilities that asset augmentation is more important, but for firms with great technological know-how that asset exploitation is of greater relevance. In their literature review Papanastassiou in drugi (2020) conclude that, apart from a few notable exceptions, empirical studies seldom provide a comprehensive picture of the relative importance of different cross-border R&D strategies. Even more so, comparative studies across countries of origin of investors and across sectors are still lacking. With our empirical analysis based on a larger unique and more recent dataset of leading R&D performers, we aim to contribute to the literature on the amount and the motives of R&D offshoring.

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2.4 Research questions

The literature review and discussion presented above lead us to the following research questions (RQ), which we intend to answer based on the data of world's top corporate R&D investors and their patenting activity:

RQ1: What are the factors behind the R&D internationalization level in the global research leaders? Do the company-related attributes or rather the characteristics specific to the company's R&D activity play a greater role in its R&D internationalization degree?

RQ2: Since companies pursue different R&D internationalization strategies in different technology fields, we ask: Are there any patterns in the employment of various R&D internationalization strategies by the multinationals?

RQ3: If there are stable types of conducting foreign R&D activities, what are the characteristics of company groups with similar R&D internationalization behavior?

3. Methodology

3.1 Data

For the company-specific analysis of worldwide R&D and patent activities of leading multinationals by technological field and target country, we combine two datasets: (1) One dataset contains information on the R&D expenditure and patent applications of the 2,000 global research leaders between 2012 and 2014 (EC-JRC/OECD COR&DIP© database, v.1. 2017 of the EC-JRC Institute for Prospective Technological Studies and the OECD Directorate for Science, Technology and Innovation); and (2) the other is the patent database of the European Patent Office with bibliographical data on patents (EPO Worldwide Patent Statistical Database PATSTAT, spring 2018). Since most countries do not publish data on the share of R&D undertaken by foreign firms according to the nationality of the firm, there is a wide strand of the literature on the foreign locations of large firms' R&D activities, exploiting the information contained in MNEs' patent documents (Cantwell in Piscitello, 2000; Cuellar in drugi, 2021; Dosso in Vezzani, 2015; Le Bas in Sierra, 2002; Patel in Vega, 1999). The advantages and drawbacks of patenting statistics as indicators of technological activities are discussed extensively elsewhere. Nonetheless, despite the pitfalls of patents highlighted in the literature, patents are strongly correlated with other indicators of innovative activity, such as R&D expenditures (Acs in Audretsch, 1989; Ambos, 2005; De Rassenfosse in drugi, 2013; Griliches, 1990; Laurens, Le Bas, Schoen in Larédo, 2015; Patel in Vega, 1999). Patent documents provide a wealth of information concerning inventors, applicants, and technical characteristics of an invention, all relevant for our analysis (Dosso in Vezzani, 2015). The main advantage of using patent information is that this data is highly disaggregated and it is available both at the firm and technology levels. Patent information on applicants and inventors allows for mapping the firm's technological activity with respect to the geographical distribution, i.e., to identify the places where the novelty creation occurred (Noailly in Ryfisch, 2015).

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To avoid double counting inventions with multiple patent applications at multiple patent offices, the evaluation is carried out on the "patent family" level. Here, patent families summarize an invention's various patent applications to the world's five largest patent offices: the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), and the United States Patent and Trademark Office (USPTO). This approach allows us to mitigate bias in many extant studies examining R&D offshoring based the patent data coming from a single patent office (as noted by Guellec in Van Pottelsberghe De La Potterie (2001) and/or Le Bas in Sierra (2002)).

Further, accordingly to the taxonomy proposed by Schmoch (2008), we map the technological orientation of the R&D activities that support invention using 35 technological fields that, in turn, can be regrouped into five macro-technological areas: electrical engineering, instruments, chemistry, mechanical engineering, and other fields. The place of invention for a patent family is equal to inventor's place of residence. Since one invention mapped in a patent family can be allocated to several inventors at different places, several patents, several applying companies, and several technology technological fields, the analysis in this paper employs fractional counts of patent families. Indeed, in case of multiple inventor countries, multiple applying firms, and/or multiple technology fields corresponding to patents of a given patent family, a fraction is attributed to its each patent (fractional counting). All weights per patent family sum up to 1[2].

Due to missing data, the final dataset contains information on patenting activities of about 1,700 companies from 2012 to 2014. Thus, compared to existing studies analyzing the offshoring activity of multinational firms, our sample is larger and more up to date (Alkemade in drugi, 2015; Laurens, Le Bas, Schoen, Villard, in drugi, 2015; Le Bas in Sierra, 2002; Patel in Vega, 1999). The companies in the dataset employ, on average, about 30,000 employees (see Table A 1). The vast majority (about three-quarters) of the firms are engaged in the sectors of high-technology manufacturing (33 percent), medium-high-technology manufacturing (27 percent), and knowledge-intensive services (16 percent). Approximately one-third of the global research leaders are based in the US, another third are in Asia (with half of these Asian firms located in Japan). About 30 percent of the companies in our sample are European companies. On average, the companies applied for about 200 patent families (fractional counts) between 2012 and 2014; 80 percent of the patent applications were in the technological areas of electrical engineering (34 percent), chemistry (26 percent), and mechanical engineering (20 percent). The mean IP intensity—measured as company's average R&D expenditure between 2012 and 2014 over its total PF number—amounts to about 15 million euros per PF. On average, the share of PF invented abroad (that is, in host countries) over company's total PF number is only 26 percent; the level of

[2] Note that from here on, both terms "patent" and "patent family" (abbr. PF) are used alternately, even though we conduct our analysis based on fractional counts of patent families.

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technological internationalization drops even to 16 percent when defining home region as company's continent.

Table 2. Descriptive Statistics: Characteristics of Companies with and without R&D Internationalization

	Companies with no R&D internationalization			Companies with R&D internationalization			
	N	Mean	SD	N	Mean	SD	
No. of employees	336	19,904	56,456	1,245	31,578	61,779	***
Economic sectors:							
High-technology manufacturing	371	0.30	0.46	1,313	0.34	0.47	
Medium-high-technology manufacturing	371	0.20	0.40	1,313	0.28	0.45	***
Medium-low-technology manufacturing	371	0.05	0.21	1,313	0.08	0.26	*
Low-technology manufacturing	371	0.08	0.27	1,313	0.09	0.28	
Construction & civil engineering	371	0.03	0.16	1,313	0.01	0.10	***
Knowledge-intensive service	371	0.22	0.42	1,313	0.14	0.35	***
Less knowledge-intensive service	371	0.05	0.22	1,313	0.02	0.15	***
Countries (company location)							
JP	371	0.19	0.40	1,313	0.17	0.37	
CN	371	0.16	0.37	1,313	0.04	0.19	***
TW	371	0.07	0.26	1,313	0.04	0.19	***
KR	371	0.07	0.25	1,313	0.02	0.15	***
Rest of Asia	371	0.01	0.12	1,313	0.02	0.14	
DE	371	0.03	0.16	1,313	0.07	0.26	***
GB	371	0.02	0.15	1,313	0.06	0.24	***
FR	371	0.02	0.14	1,313	0.04	0.21	**
CH	371	0.00	0.05	1,313	0.04	0.19	***
NL	371	0.01	0.07	1,313	0.02	0.15	**
Rest of Europe	371	0.05	0.23	1,313	0.10	0.30	**
US	371	0.33	0.47	1,313	0.34	0.47	
Rest of North America	371	0.01	0.07	1,313	0.01	0.11	
Rest of the world	371	0.01	0.09	1,313	0.02	0.14	
No. of patent families	363	17.14 (4.00)	36.18	1,305	252.10 (47.00)	891	***
Patents share in … over total number of company patents							
Electrical engineering	363	0.37	0.41	1,305	0.33	0.35	
Instruments	363	0.10	0.20	1,305	0.15	0.20	***
Chemistry	363	0.29	0.39	1,305	0.25	0.32	***
Mechanical engineering	363	0.16	0.28	1,305	0.22	0.27	***
Other fields	363	0.06	0.19	1,305	0.06	0.14	***
Level of technological internationalization I (share of PF invented abroad over company's total patent number)	363	0.00	0.00	1,305	0.34	0.32	***
Level of technological internationalization II (share of PF invented on the other continent over company's total PF number)	363	0.00	0.00	1,270	0.20	0.24	***

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IP intensity (company's R&D expenditure (mean value over the period 2012-14; in EUR million) over its total PF number)	363	34.39 (9.36)	125.95	1,305	9.39 (2.12)	34.08	***
Technological diversification	363	0.53	0.26	1,305	0.69	0.19	***

*Note: N and SD refer to the number of observations and standard deviations, respectively. Reported are some median values in the parentheses. Mann Whitney U test results on differences between the two groups of companies--with and without R&D internationalization: * p<0.10, ** p<0.05, *** p<0.01*

Interestingly, however, a considerable number of global research leaders—i.e., 363 companies in our dataset—conduct their R&D activities solely in their home country. Table 2 presents the characteristics of leading R&D performers with and without R&D internationalization activity. Companies with no R&D operations in foreign countries have a significantly smaller number of employees, on average, and are more frequently engaged in the service and construction sectors than firms with international R&D activity. Regarding firm nationalities, we find that the proportion of US enterprises is about one-third in both firm groups. The group of global research leaders with no R&D operations abroad are dominated by Asian companies (52 percent); European ones amount to only 13 percent. Further, 33 percent of firms with R&D activity overseas are headquartered in Europe; 29 percent in Asia. According to differences regarding firm size between the two company groups, we find that leading R&D performers with international R&D have a significantly larger PF portfolio that their peers with R&D operations carried out in the home country only (on average, about 252 and 17 PF, respectively). On average, about one-third of PF that both company groups applied for are assigned to electrical engineering. Enterprises with foreign R&D activity applied more frequently for patents in the technological areas of mechanical engineering and instruments. Nevertheless, the fraction of patents in the chemistry fields is significantly higher in the group of companies with national R&D operations only. Moreover, our findings reveal an interesting result regarding the differences in the IP intensity between the global research leaders with no R&D international activity and those carrying out R&D abroad. The former group of firms exhibit higher mean and median values of R&D expenditures per PF than the latter. The IP intensity reflects to some extent features such as the complexity of the products, as well as the costs of identifying and developing new technological solutions (Daiko in drugi, 2017). In that way, the developed products of the usually smaller companies conducting R&D activities in their home country only appear to show a higher degree of complexity and innovation.

3.2 Variables and Estimation Methods

We conduct our empirical analysis in three steps described below. Note here that due to a short observation period, we conduct a cross-sectional analysis.

Step 1: Investigating determinants of the company internationalization level (fractional response models).

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In the first step of our analysis, we examine factors behind the R&D internationalization level of the global research leaders. The dependent variable ($Tech\_int$) is measured as the share of patents invented abroad in the company's total patent number between 2012 and 2014. Since the dependent variable takes values between 0 and 1 (with the possibility of observing values at the boundaries), we apply the fractional probit estimator developed by Papke in Wooldridge (1996). Formally, our model can be expressed as

$$Tech\_int_{ij} = \beta_0 + \beta_1 Size_{ij} + \beta_2 Sector_{ij} + \beta_3 Country_{ij} + \beta_4 Tech_{ij} + \beta_5 Pat_{ij} + \varepsilon_{ij}$$

where j is the dependent variable index, i is the company index.

$Size$: On the one hand, geographical dispersion of firm R&D activities provides access to various knowledge sources. However, on the other hand, acquiring know-how in foreign countries bears not just additional transaction and organizational costs, but also faces managerial and cognitive constraints, due to growing coordination problems (Ardito in drugi, 2018; Ding in drugi, 2021; Rahko, 2015; Singh, 2008). Thus, we include firm size to account for the heterogeneity of the global research leaders in terms of their resources and capabilities. Specifically, the vector $Size$ covers two variables measuring the company size: the logarithm of the number of employees and its square value. This allows us to account for possible nonlinear effects of overall company's size on its technological internationalization.

$Sector$: The vector $Sector$ captures the impact of company economic sectors. According to the sector classification based on NACE Rev. 2 by Eurostat,[3] we include dummy variables for medium-high-technology manufacturing, medium-high-technology manufacturing, medium-low-technology manufacturing, low-technology manufacturing, construction and civil engineering, knowledge-intensive services, and less knowledge-intensive services; the sector of high-technology-manufacturing is the reference category.

$Country$: To account for country-specific effect, we consider several dummy variables for company's home country and/or region—Japan (JP), Republic of China (CN), Taiwan (TW), South Korea (KR), the rest of Asia, Germany (DE), Great Britain (GB), France (FR), Switzerland (CH), Netherlands (NL), the rest of Europe, the rest of North America, and the rest of the world. The reference category refers to the United States of America (US).

$Tech$: Similar to Le Bas in Patel (2007), we include the company's core technological competences. The vector $Tech$ consists of dummy variables revealing the main technological area of the company's patenting activities. The respective variables take the value of 1 if the share of patents applied by the company in a specific technology area (as proposed by Schmoch (2008)) in its total patent number is greater than fifty percent. Thus, we include dummies for the main

[3] See also https://ec.europa.eu/eurostat/de/web/nace-rev2.

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technological orientation in instruments, chemistry, mechanical engineering, other fields, and no main area. The technology area of electrical engineering is the reference category.

Pat: Further, the vector Pat contains three variables regarding the company's patenting activities: (1) We include the logarithm of the company's patent number as a proxy for the size of a company's R&D portfolio. Indeed, companies with a larger patent numbers should exhibit a higher level of R&D internationalization (Le Bas in Patel, 2007). (2) To account for the fact that various industries and/or companies develop products with different features, we include the IP intensity—the logarithm of the company's average R&D expenditure in the period 2012-2014 (in EUR millions) over its total PF number—which is considered as a measure of the product complexity as well as the costs of identifying and developing new technological solutions (Daiko in drugi, 2017). (3) Since a company's technological internalization degree may be positively related to its level of technological diversification (Cantwell in Piscitello, 2000; Hall in drugi, 2001; Le Bas in Patel, 2007), we account for the dispersion of a company's patents across technological classes. In accordance with other studies, the level of technological diversification of a firm is measured here as $1 - Herfindhal\ index$ (García-Vega, 2006; Le Bas in Patel, 2007; Rahko, 2015). The Herfindhal index is calculated as the sum of the squares of the firm's patent shares in 35 technology fields defined by Schmoch (2008); it takes values between 0 and 1, the lower the value, the more technologically diversified the company.

Finally, β_0 represents the constant, β_1 through β_5 indicate the vectors of coefficients, and ε is the error term.

Step 2: Finding of company groups based on similar employment of internationalization strategies (cluster analysis)

To explore the R&D internationalization behavior of the world's top research companies, we first need to identify the R&D internationalization strategies employed by the multinationals for each technological field of their R&D activities. To this end, we apply the approach used in the previous studies, in particular by Patel in Vega (1999), Le Bas in Sierra (2002) and Laurens, Le Bas, Schoen in Larédo (2015) (see also Section 2). Based on the underlying patent data, we calculate the revealed technological advantage index values (RTA) to determine which technological fields are the strengths or weaknesses of a company (1) in the home country and (2) in the host countries. Each internationalization strategy in a technology field is characterized by a binomial relation between a firm's RTA in its home country and the RTA of the host country in which the respective enterprise carries out a part of its R&D activities (see Table 1). Specifically, The RTA index measures the relative concentration of invention activity (patent families p) of a company on specific technologies in comparison to a population of companies. It is defined as follows:

$$RTA_{ti} = \left(p_{ti}/\sum_t p_{ti}\right)/\left(\sum_t p_{ti}/\sum_{ti} p_{ti}\right)$$

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In the equation, t stands for the technological field's index and i for the index of the respective company. To classify the internationalization strategies, we measure the technological advantage of an individual company at home (RTA home) and the technological advantage of all the companies in a host country (RTA host). Finally, according to the framework proposed by Patel in Vega (1999), we determine the shares of patents acquired via different internationalization strategies—HBE, HBA, TS, and/or MS—in the total patent number at the company level.

Further, as discussed earlier (see Section 2), multinationals often do not just follow one specific internationalization strategy, rather they simultaneously employ a mix, i.e., they combine the four strategies—HBE, HBA, TS and MS—to varying extents depending on their specialization across technology fields. Hence, to synthesize the highly heterogenous multinational firms into a manageable and interpretable set of typologies based on their engagement in internationalization strategies, we use the cluster analysis approach. In this case, global research leaders with as similar as possible internationalization patterns of research activities are clustered into groups so as to make differences between the groups as large as possible. Note that companies with no patents abroad are excluded from this analysis step, leaving a total of 1,305 companies with foreign R&D activities used in the cluster analysis. Specifically, based on the company's shares of patents acquired via four internationalization strategies—HBE, HBA, TS and/or MS—in the total patent number, we carry out the cluster analysis using a traditional, well-established clustering approach—the k-means clustering algorithm. Note that k-means clustering method requires specifying the initial partition, i.e., the number of clusters K (and optionally cluster centers as input parameters). To determine the optimal solution regarding the cluster number K, we apply firstly two other clustering algorithms—the two-step cluster procedure and hierarchical clustering. One of the advantages of the rather rarely used two-step clustering procedure is that the number of clusters K can be determined automatically by the algorithm (on the basis of the BIC or AIC criterion) (Chiu in drugi, 2001). In our case, the two-step-clustering procedure reveals three company groups. Additionally, we conduct a sensitivity analysis using a further traditional approach—hierarchical clustering. Our results appear to be robust to employing the two-step clustering procedure. Hence, we cluster the global research leaders owing patents invented abroad into three company groups applying the k-means clustering algorithm.

Step 3: Analyzing characteristics of the company groups (multinomial logit model)

To interpret the identified clusters and check the internal consistency of our findings from the previous analysis step, we first calculate descriptive statistics on further attributes of the company groups). Then, we estimate a multinomial logit model that relates the likelihood of being assigned to each specific cluster k $(where\ k = 1,2,3)$ to various firm characteristics and its research activities. Thus, our dependent variable CL is here nominally scaled, where $CL = k$ if a firm belongs to a specific cluster k. Our model is as follows:

$$CL_i = \beta_0 + \beta_1 Size_i + \beta_2 Sector_i + \beta_3 Country_i + \beta_4 Tech_i + \beta_5 Pat_i + \beta_6 Tech\_int_i + \varepsilon_i$$

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where i is the company index. Note that the independent variables included the vectors $Size$, $Sector$, $Country$, $Tech$, and Pat are identical as in the model presented in the first analysis step. Moreover, we add the level of technological internationalization—a company's share of PF invented in host countries over its total patent number—to examine whether company clusters are different with respect to the internationalization degree of research activities.

4. Results

4.1 Factors Influencing the R&D Internationalization Level in the Global Research Leaders

Table 3 presents the estimation results of the factional response models: Model 1 includes company-related characteristics only, in Model 2 we consider also the variables relating to company's patenting activities. Though, in general, the companies in our sample are large, our findings show that firm size is still an important determinant of its level of technological internationalization. Indeed, we find a U-shaped relationship between the size and the internationalization degree. This reveals that, on the one hand, smaller companies tend to have high levels of internationalization. This is related to the fact that smaller firms have a rather small number of PF, thus, even few PFs invented in host regions result in relatively high shares of PF invented in host regions in total PF number. On the other hand, particularly large global research leaders exhibit high levels of technological internationalization. Surprisingly, we find hardly any differences in the internationalization degree between various economic sectors. Regarding the effects of a firm nationality, the results reveal that Asian research leaders—particularly those from Japan, China, and South Korea—tend to exhibit a lower level of technological internationalization compared to the US companies (reference category). Similarly, the internationalization degree of German companies is lower that of the US firms. Nonetheless, the results show that, compared to US, companies based in relatively small countries—like Great Britain, Switzerland, the Netherlands, the rest of European countries, and the other North American countries (mostly Canada)—have a higher degree of R&D internationalization. This finding is in line with the findings of earlier studies (Danguy, 2017; Laurens, Le Bas, Schoen, Villard, in drugi, 2015). Another surprising result is that neither the concentration of patent activities in a specific technological area nor the level of technological diversification of PF across the 35 technological fields have a significant impact on a company's degree of internationalization. Finally, the size of a firm's patent portfolio—measured by the logarithm of the company's patent number—is positively associated with its engagement in foreign R&D activities. This is in line with prior research results (Le Bas in Patel, 2007).

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Table 3. Fractional response model estimation results: Determinants of the level of technological internationalization

	Share of patents invented abroad			
	Model 1		Model 2	
	Coeff.	S.E.	Coeff.	S.E.
No. of employees (ln)	0.405***	(0.090)	0.414***	(0.094)
No. of employees (square ln)	-0.019***	(0.005)	-0.021***	(0.005)
Medium-high-technology manufacturing (d)	-0.111*	(0.058)	-0.091	(0.066)
Medium-low-technology manufacturing (d)	0.114	(0.095)	0.169*	(0.101)
Low-technology manufacturing (d)	-0.029	(0.087)	0.001	(0.096)
Construction & civil engineering (d)	-0.466	(0.324)	-0.394	(0.330)
Knowledge-intensive service (d)	-0.110	(0.074)	-0.093	(0.080)
Less knowledge-intensive service (d)	-0.384**	(0.186)	-0.321*	(0.187)
JP (d)	-0.920***	(0.068)	-0.914***	(0.071)
CN (d)	-0.415***	(0.128)	-0.363***	(0.134)
TW (d)	-0.692***	(0.126)	-0.657***	(0.135)
KR (d)	-0.187	(0.524)	-0.197	(0.507)
Rest of Asia (d)	0.214	(0.204)	0.279	(0.207)
DE (d)	-0.190**	(0.076)	-0.195**	(0.081)
GB (d)	0.892***	(0.106)	0.915***	(0.107)
FR (d)	0.135	(0.103)	0.150	(0.105)
CH (d)	0.868***	(0.132)	0.872***	(0.133)
NL (d)	1.196***	(0.182)	1.205***	(0.181)
Rest of Europe (d)	0.455***	(0.084)	0.473***	(0.086)
Rest of North America (d)	0.704**	(0.285)	0.725**	(0.282)
Rest of the world (d)	0.172	(0.164)	0.208	(0.165)
Instruments (d)			0.025	(0.095)
Chemistry (d)			-0.014	(0.076)
Mechanical engineering (d)			0.018	(0.088)
Other fields (d)			0.052	(0.166)

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No main area (d)			-0.008	(0.083)
No. of patent families (ln)			0.059**	(0.028)
IP intensity (ln)			0.039	(0.031)
Technological diversification			-0.099	(0.163)
Constant	- 2.635***	(0.395)	- 2.741***	(0.443)
R-squared	0.132		0.133	
Chi2	555.4***		556.2***	
N	1,581		1,581	

Notes: Reported are the coefficients and standard errors in parentheses. N is the number of observations. (d) denotes dummy variables. The reference categories are US companies, the sector of high-technology manufacturing, and the technological area of electrical engineering 2) * p<0.10, ** p<0.05, *** p<0.01

4.2 Patterns in the Employment of Various R&D Internationalization Strategies by the Multinationals

Based on the company's shares of patents acquired via four internationalization strategies—HBE, HBA, TS and/or MS—in the total patent number, the cluster analysis reveals three groups of companies with similar R&D behavior patterns.

Table 4. Cluster Analysis Results: Comparison of Company Groups according to Patent Shares in the Respective Internationalization Strategies over Number of Company Patents Invented Abroad (as Percentages)

	Cluster 1		**Cluster 2**		**Cluster 3**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
HBA	<u>0.86</u>	0.12	0.14	0.13	<u>0.47</u>	0.16
HBE	0.09	0.09	<u>0.77</u>	0.17	<u>0.33</u>	0.14
TS	0.03	0.05	0.04	0.09	0.10	0.16
MS	0.02	0.05	0.04	0.09	0.10	0.14
N	505		271		529	
Cluster name	Companies mainly employing the HBA strategy		Companies mainly employing the HBE strategy		Companies with mixed internationalization strategies	

Notes: N and SD refer to the number of observations and standard deviations, respectively. Underlined figures signal the (one or two) most important internationalization strategies.

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Table 4 presents the distribution of companies with foreign R&D activities in the three clusters according to the four internationalization strategies. The first cluster consists of 505 firms with a very high PF share in the HBA strategy (86 percent, on average). Accordingly, we label these enterprises *companies mainly employing the HBA strategy*. The second cluster is the smallest, including 271 firms that reveal a high PF share in the HBE strategy (the average value is 77 percent). We call this group *companies mainly employing the HBE strategy*. The third and last cluster includes 529 companies that predominantly employ the two internationalization strategies of HBA and HBE.[4] Moreover, the PF shares in the TS and MS strategies of 10 percent in each case, on average, are quite high compared to other clusters. Consequently, this group is referred to as companies with mixed internationalization strategies.

Table 5 sets out the model estimation results on further characteristics of the found company clusters (Table A 2 in the Appendix presents descriptive statistics). Overall, compared to the analysis on the determinants of a company's internationalization degree (see Section 4), we find that the features related to firm's R&D activities (like diversification of its PF across technological fields, allocating the major proportion of its R&D resources in a selected technological area, and the size of its PF portfolio) play an even greater role in explaining differences between the determined groups of global research leaders than company-related attributes (such as firm size, economic sector, or location in a specific country). The found clusters of enterprises with international R&D activities can be characterized as follows.

Cluster 1—Companies mainly employing the HBA strategy: 40 percent of 505 firms in this cluster are headquartered in Europe; one-third—in the US. Only 23 percent of them are based in Asia, whereas Japanese enterprises are underrepresented compared to other firm groups (see Table A 2). Further, companies mainly employing the HBA strategy exhibit the highest level of R&D internationalization. Indeed, the share of PF with foreign inventors in the total PF number is 42 percent, on average. Further, our model estimation results also show that the higher the degree for technological internationalization, the higher probability of being assigned to this cluster. These firms predominantly apply for patents in the technological areas of chemistry, electrical engineering, and mechanical engineering (on average, 31, 25, and 21 percent of a company's PF, respectively) in the 2012 to 2014 period. However, patents in electrical engineering are less frequently represented in this group (see Table A 2). Accordingly, the effects of dummies for the main technological areas of company's PF— instruments, chemistry, mechanical engineering, other fields, and no main area—are highly significant (see Table 5). Thus, companies allocating its PFs predominantly in one of these technological areas are more likely to be assigned to cluster 1,

[4] In a case study of Novozyme, a leading European MNE in the highly globalized biotech sector, Haakonsson, S. J. in Ujjual, V. (2015). Internationalisation of R&D: New insights into multinational enterprises' R&D strategies in emerging markets. *Management Revue*, *26*(2), 101-122. show how MNEs can use a combination of augmenting and exploiting strategies in emerging markets.

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compared to firms concentrating their patenting activities in the electrical engineering area (reference category).

Table 5. Multinomial logit model estimation results: Characteristics of company groups

	Cluster 1	Cluster 2	Cluster 3
No. of employees (ln)	0.057	-0.059	0.001
	(0.069)	(0.052)	(0.070)
No. of employees (square ln)	-0.003	0.003	0.000
	(0.004)	(0.003)	(0.004)
Medium-high-technology manufacturing	0.003	0.042	-0.046
	(0.047)	(0.040)	(0.044)
Medium-low-technology manufacturing	-0.064	0.064	0.000
	(0.066)	(0.061)	(0.066)
Low-technology manufacturing	-0.040	0.123**	-0.083
	(0.061)	(0.062)	(0.059)
Construction & civil engineering	0.280*	-0.065	-0.216*
	(0.153)	(0.099)	(0.126)
Knowledge-intensive service	0.090*	-0.004	-0.087*
	(0.054)	(0.039)	(0.049)
Less knowledge-intensive service	-0.046	0.055	-0.009
	(0.107)	(0.095)	(0.106)
JP	-0.005	0.099**	-0.094**
	(0.051)	(0.046)	(0.045)
CN	-0.059	0.096	-0.037
	(0.086)	(0.075)	(0.086)
TW	0.093	0.030	-0.123
	(0.101)	(0.072)	(0.077)
KR	0.106	0.306	-0.412***
	(0.375)	(0.375)	(0.016)
Rest of Asia	0.155	-0.008	-0.147
	(0.115)	(0.092)	(0.097)
DE	-0.027	0.038	-0.011
	(0.062)	(0.055)	(0.061)
GB	-0.063	-0.055	0.118
	(0.066)	(0.047)	(0.072)
FR	0.072	-0.021	-0.051
	(0.081)	(0.062)	(0.073)
CH	0.167*	-0.145***	-0.022
	(0.087)	(0.042)	(0.085)

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NL	0.060	0.145	-0.205***
	(0.107)	(0.113)	(0.079)
Rest of Europe	0.030	-0.026	-0.004
	(0.057)	(0.044)	(0.056)
Rest of North America	0.093	0.165	-0.257**
	(0.197)	(0.190)	(0.131)
Rest of the world	0.118	0.054	-0.171*
	(0.118)	(0.100)	(0.095)
Instruments	0.299***	-0.155***	-0.144***
	(0.057)	(0.023)	(0.054)
Chemistry	0.315***	-0.180***	-0.134***
	(0.050)	(0.024)	(0.046)
Mechanical engineering	0.242***	-0.108***	-0.133***
	(0.057)	(0.030)	(0.051)
Other fields	0.388***	-0.129***	-0.259***
	(0.071)	(0.036)	(0.062)
No main area	0.133**	-0.066**	-0.067
	(0.058)	(0.033)	(0.051)
No. of patent families (ln)	0.001	-0.062***	0.061***
	(0.019)	(0.016)	(0.019)
IP intensity (ln)	0.029	-0.027*	-0.003
	(0.020)	(0.016)	(0.019)
Technological diversification	-0.509***	-0.121	0.630***
	(0.109)	(0.079)	(0.119)
Level of technological internationalization	0.243***	-0.170***	-0.074
	(0.059)	(0.048)	(0.061)
R-squared		0.127	
Chi2		335.1***	
N		1,245	

*Notes: Reported are the marginal effects and standard errors in parentheses. N is the number of observations. (d) denotes dummy variables. The reference categories are US companies, the sector of high-technology manufacturing, and the technological area of electrical engineering 2) * p<0.10, ** p<0.05, *** p<0.01*

Additionally, the average level of technological diversification in this firm group appears to be the lowest compared to other clusters of firms conducting R&D abroad. Nonetheless, the findings from the model estimation reveal that enterprises exhibiting a greater technological diversification are more likely to be assigned to this cluster and, thus, predominantly employ the HBA strategy.

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Cluster 2—Companies mainly employing the HBE strategy: In this smallest cluster, firms located in Asia are overrepresented (36 percent of 271 companies), with 21 percent headquartered in Japan. The US represents 35 percent of global research leaders in this groups. European companies are less frequently represented (24 percent—see Table A 2). Yet, the model estimation results show that the probability of being a member of this firm group is only significantly higher (lower) for companies located in Japan (Switzerland) than for those based in the US (reference category; see Table 5). Further, we also find that enterprises engaged in low-technology manufacturing are more likely to be assigned to this group in comparison with those in high-technology manufacturing (reference category). Compared to the other firm groups, companies in cluster 2 have the lowest level of R&D internationalization (only 27 percent of PF with foreign inventors in the total PF number, on average; see Table A 2). The model estimation results also reveal a significantly negative relationship between the level of technological internationalization and the probability of being assigned to this cluster (see Table 5). Hence, those global research leaders with lower involvement in foreign R&D activities are more likely to mainly employ the HBE strategy. Similarly, the variable IP intensity of a company is significantly negatively associated with the probability of being a member of cluster 2 at the 10 percent level. That is the higher the complexity of company's inventions the less likely it focuses on the HBE strategy.

Further, the descriptive statistics show that companies in this group have the smallest number of PF, on average, but the median value reveal that their portfolio size is comparable to that of the cluster 1, i.e., companies mainly employing the HBA strategy (see Table A 2). Based on the econometric analysis, we find a negative relationship between the patent portfolio size and the probability of being assigned to cluster 2 (see Table 5). In other words, the fewer patents a firm applies for, the more likely it concentrates on the HBE strategy. The results also reveal significantly negative effects of dummies for main technological areas of patenting activities: the impact of technological diversification is here insignificant (see Table 5). Consequently, compared to the concentration on other technological areas, companies allocating the vast proportion of their R&D operations in the technological area of electrical engineering are more likely to be assigned to cluster 2. Indeed, the global research leaders employing the HBE strategy applied for patents in electrical engineering more frequently than other firm groups (see Table A 2).

Cluster 3—Companies with mixed internationalization strategies: Approximately one-third of the 529 global research leaders in this cluster are headquartered in Asia, Europe, and the US, respectively (see Table A 2). The model estimation results reveal that some country-specific effects appear to significantly influence the probability of assignment to this cluster (see Table 5). Companies located in Japan, South Korea, the Netherlands, and the rest of North Amerika (almost exclusively Canada) are less likely to mix the internationalization strategies in comparison to US companies. Compared to other firm groups, a particularly large proportion (about 70 percent) concentrates on the sectors of high-technology manufacturing and medium-high-technology manufacturing (see Table A 2). Further, these companies are larger in terms of the number of

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employees and exhibit the highest level of technological diversification of patenting activity among all firm groups. Nevertheless, they show the lowest value of IP intensity (about 6.8 million EUR per PF, on average; the median value is only 1.7 million per PF). The findings from the model estimation also reveal a positive relationship between the size of a firm's PF portfolio and the probability of the company to be assigned to cluster 3 (see Table 5). Additionally, global research leaders with a greater technological diversification are more likely to be a member of this firm group. Compared to other groups of companies operating in the field of R&D in the foreign countries, the average PF share in the technological area of electrical engineering (chemistry) is in this cluster relatively high (low) (Table A 2). In fact, enterprises concentrating their patenting activities in the areas of instruments, chemistry, mechanical engineering, and other fields are less likely to mix the four internationalization strategies than those focusing on the electrical engineering area (Table 5).

5. Discussion

5.1 R&D Internationalization Level of Leading R&D Performers

Our results reveal that about a fifth of global research leaders do not employ inventors abroad, thus, they concentrate the patent-relevant R&D in their home country. The level of technological internationalization of MNEs in our large firm sample for the 2012-2014 period is higher than that in existing studies for earlier periods (Laurens, Le Bas, Schoen, Villard, in drugi, 2015; Le Bas in Sierra, 2002). Despite the different company samples and the different patent indicators used, this points to an increase in the intensity of R&D internationalization. Regarding the effects of a firm's nationality, our findings are consistent with prior studies (Laurens, Le Bas, Schoen in Larédo, 2015; Le Bas in Sierra, 2002; Patel in Vega, 1999; Wei in Nguyen, 2020). We find that Asian research leaders—particularly those from Japan, China, and South Korea—tend to exhibit a lower level of technological internationalization than US companies. Similarly, the internationalization degree of German companies is lower than that of the US firms. On the contrary, companies based in smaller European countries—like Great Britain, Switzerland, and the Netherlands—have a higher R&D internationalization degree than US companies.

Like Le Bas in Sierra (2002), we find that the size of a firm's patent portfolio, as a proxy of its R&D capacity, is positively associated with its engagement in foreign R&D activities. Moreover, our results show that firm size is still an important determinant of its level of technological internationalization. Indeed, we find a U-shaped relationship between size and the degree of internationalization. This indicates that, on the one hand, especially smaller firms internationalize their R&D activity to a relatively high extent. In fact, given that smaller companies have a rather small amount of PF, even a few PFs invented abroad result in relatively high shares of PF invented in host regions in their total PF number. On the other hand, particularly larger global research leaders holding greater PF portfolios exhibit a higher involvement in technological internationalization. To master the development of numerous inventions, commonly in various

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technological fields, they must rely on the acquisition of expertise and know-how from centers of excellence around the world (Dell'anno in drugi, 2018; Freire in Gonçalves, 2021; Liu in Uzunidis, 2021; Moncada-Paternò-Castello in drugi, 2011). Finally, though geographical dispersion of company's R&D operations provides access to different knowledge sources, it also bears additional transaction and organizational costs, as well as leads to managerial and cognitive constraints resulting from the growing coordination effort (Ardito in drugi, 2018; Nurcholis, 2021; Singh, 2008). Hence, medium sized global research leaders focus more of their R&D operations in the home country to realize the efficiency advantages due to co-location of parties engaged in innovative activities. Surprisingly, we find no evidence for an influence of the breadth of the company's technological expertise on its degree of internationalization. Neither the concentration of patent activities in a specific technological area nor the level of technological diversification have a significant impact on a company's internationalization degree.

Our results reveal also that MNEs carrying out R&D activity abroad exhibit a lower IP intensity—which is considered to be a proxy for complexity of company products (measured as mean R&D expenditure per PF) as well as the costs of identifying and developing new technological solutions (Daiko in drugi, 2017)—than those with no R&D international activity. Thus, in other words, companies conducting R&D solely in the home country tend to develop inventions of higher complexity than global research leaders spreading their R&D activity across countries. This finding is in line with a wide body of research highlighting the role of the 'proximity factor' and face-to-face communication in the processes of creation and transfer knowledge, especially tacit knowledge (see, e.g., Boyle in drugi, 2016; Camagni, 1991; Feldman, 1999; Fujita in drugi, 2001; Lundvall, 1992).

5.2 Internationalization Strategies of Leading R&D Performers

The literature found two main drivers of R&D internationalization of firms. With their R&D abroad firms either adapt their products to local markets following a home-based asset-exploiting strategy or they look for complementary technologies abroad to augment their technological capabilities. We use a framework suggested and applied first by Patel in Vega (1999) to identify four R&D internationalization strategies for each pair of technology field and host country. Applying this approach to analyze developments that took place in the 1990s, Le Bas in Sierra (2002) find increasing shares of knowledge augmenting motives and a decreasing share of market-oriented motives to only exploit the knowledge of the home base. The results of Laurens, Le Bas, Schoen, Villard, in drugi (2015) tend to contradict these postulates. The comparison of the overall situation in 2003–2005 with the one monitored one decade before shows a slight, but significant, decrease in the total weight of the HBA motives associated with a slight increase of the share of HBE motives. The authors see a new equilibrium between HBA and HBE as the two dominant motivations. Our study, relying on a larger data set for the 2012 to 2014 period, confirms the former results on the dominance of knowledge augmenting motives. Table A 1 in the Appendix

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sets out aggregated fractional PF counts according to the R&D internationalization strategies. The companies in our dataset predominantly employ the HBA (55.2 percent of patent weights) and HBE (26.9 percent of patent weights) strategies. Only 9.2 and 8.8 percent of the patent weights point to TS and MS strategies, respectively. In contrast to the studies of Laurens, Le Bas, Schoen, Villard, in drugi (2015) and Picci in Savorelli (2012), our results indicate not only the dominance of HBA strategies but a significantly increased share of these HBA strategies compared to earlier studies. This growing share of HBA motivations is mainly at the expense of both TS and MS strategies.

In our view, in accordance with former studies, R&D internationalization is indeed driven mostly by home-base-augmenting motives. The great and recently increased importance of the HBA strategies shows that companies mainly attempt to acquire complementary knowledge in the internationalization of R&D at foreign locations. Even with the second strongest, the market oriented HBE strategy, the technological strength at the home location is the starting point for internationalization. Thus, based on more recent firm data, our findings support the results of Patel in Vega (1999), in that the large majority of firms tend to locate their R&D activity abroad in the technological areas where they also have a domestic advantage.

5.3 Typical Patterns in the Internationalization Strategies of Groups of Leading R&D Performers

Unlike most existing studies, we take into consideration that companies can simultaneously pursue multiple R&D internationalization strategies. Using a k-means clustering approach, we find three clusters of companies with different weights of the four R&D internationalization strategies. The 505 companies in the first cluster primarily pursue HBA strategies. Their R&D activity is comparatively the most internationalized, technologically focused, and less diverse. Companies of this cluster are significantly less specialized in the technologies in the electrical engineering area—which is the largest technology area making up about 45 percent of patenting activity of all world's top corporate investors. The proportion of firms headquartered in Europe (Asia) in this group is higher (lower) than in other clusters. Note that about one-third of companies assigned to each group are based in the US.

The second and smallest cluster comprises only 271 enterprises employing predominantly HBE strategies. These firms have fewer patents, are engaged in R&D internationalization activity to a lesser extent and belong to the sector of low-technology manufacturing more frequently. Companies located in Asia are overrepresented in this group and European companies are less frequently represented.

The third cluster contains 529 research based MNEs and is therefore about the same size as the first cluster. Companies in this group employ a strategy mix of HBA and HBE. They are more often engaged in the sectors of high-technology and less frequently in low-technology manufacturing. They are not only larger (in terms of number of employees) but also much more

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technologically diversified than leading R&D performers in the other groups. Nevertheless, they show the lowest value of IP intensity. The interpretation of this fact is not clear. This could indicate that these companies develop inventions of lower complexity. However, it could also show that they are particularly efficient at conducting research in areas with high levels of competition and patent density.

Overall, compared to the analysis on the factors behind company's internationalization level, our model estimation results reveal hardly any significant effects of firms' home countries on the probability of being assigned to one of the determined clusters. Nevertheless, we find that the features related to firm's technology portfolio (like diversification of its PF across technological fields, allocating the major proportion of its R&D resources in a selected technological area, and the size of its PF portfolio) play an even greater role in explaining differences between the determined groups of global research leaders than company-related attributes (such as firm size, economic sector, or location in a specific home country).

6. Conclusion, Limitations, and Future Research Directions

By developing a new dataset of the patent portfolios of the leading corporate R&D investors worldwide in the 2012-2014 period, we contribute to the debate on the internationalization of their R&D activity. Our firm sample of 1,700 MNEs is considerably larger than the samples used in earlier studies on the internationalization of R&D. Furthermore, we use data on patent families to avoid double counting inventions with multiple patent applications at multiple patent offices. In our view, there is a clear dominance of and an evolution toward the motives of knowledge augmenting, even if aiming at exploiting the home knowledge base to support market development remains prevalent. Offshoring of R&D is used by MNEs predominantly to acquire complementary technological knowledge (HBA). The most interesting research locations abroad for MNEs are therefore increasingly those with a strong research landscape. The advantages built at home are at the core of the most important internationalization strategies of firms (HBA and HBE). Therefore, the increased attraction of foreign R&D locations is no reason for concern regarding the perceived hollowing-out of the national innovation systems. Moreover, we find that with one fifth a considerable number of the world's top corporate investors conduct their R&D operations only in their home country. In terms of policy implications, we agree with Le Bas in Sierra (2002), pronouncing that also in an era of increasing R&D internationalization, what happens in the home country of MNEs remains of great relevance. Furthermore, the most important home countries of the leading internationalized R&D investors are also the most important hosts. Thus, both the companies and the countries actively engaging in the R&D internationalization are likely to benefit from that process.

This study has some limitations that also provide interesting new lines for future inquiry. First, while patent data are a useful mean of measuring inventive activities, they still account only for patent relevant R&D. In fact, patent indicators might underestimate the weight of market-oriented

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internationalization strategies because they do not capture further development activities, i.e., adapting products to special customer requirements. Thus, future research may consider other, more market-oriented measures of intellectual property of the world's top corporate R&D investors, like trademarks and industrial designs. Second, analyzing the determinants of the level of foreign R&D involvement of global research leaders and patterns in pursuing various R&D internationalization strategies, we focus our arguments on the impacts of the company-specific characteristics and features related to their R&D activities. However, further studies may investigate other drivers behind corporate R&D internationalization, such as the managers' abilities and/or willingness to acquire external technologies. Regarding the result that a considerable number of the world's top corporate investors only conduct their R&D operations in their home country, future research should also provide more insight into the motives of pursuing the non-internationalization strategy. Finally, this study is a cross-sectional analysis. Indeed, using panel data over a longer period would allow to explore the determinants of geographical and technological distribution of the R&D activity of worldwide research leaders over time.

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Appendix

Table A 1. Comparison of patent shares in the respective internationalization strategies over number of company patents invented abroad (as percentages) in different studies

	Patel in Vega (1999)	Le Bas in Sierra (2002)		Laurens, Le Bas, Schoen, Villard, in drugi (2015)		Our data
	1990-1996	1988–1990	1994–1996	1994-1996	2003-2005	2012-2014
HBA	39.2	45.4	47.4	43.3	42.5	55.2
HBE	36.9	31.0	30.1	35.7	39.4	26.9
TS	10.5	12.8	13.1	11.7	9.8	9.2
MS	13.4	10.8	9.5	9.3	8.3	8.8
Patent indicator	US patents	EURO-PCT' registered by the European Patent Office		Worldwide priority patent applications		Patent families of applications to the world's five largest patent offices
N	220	345	345	946	946	1,305

Note: [1] The level of a company's internationalization is measured here as its share of PF invented in host counters in its total PF number. [2] The sample in the study by Laurens, Le Bas, Schoen, Villard, in drugi (2015) includes only European firms.

Table A 2. Descriptive statistics: Characteristics of company groups

	All companies			Cluster 1			Cluster 2			Cluster 3			
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	
No. of employees	1,581	29,097	60,857	481	26,254	43,816	257	22,087	55,447	507	41,440	76,396	***
Economic sectors:													
High-technology manufacturing	1,676	0.33	0.47	505	0.31	0.46	271	0.32	0.47	529	0.38	0.49	**
Medium-high-technology manufacturing	1,676	0.27	0.44	505	0.27	0.44	271	0.27	0.45	529	0.31	0.46	
Medium-low-technology manufacturing	1,676	0.07	0.25	505	0.07	0.25	271	0.08	0.27	529	0.08	0.28	
Low-technology manufacturing	1,676	0.09	0.28	505	0.1	0.3	271	0.11	0.31	529	0.06	0.24	**
Construction & civil engineering	1,676	0.01	0.11	505	0.01	0.12	271	0.01	0.09	529	0.01	0.08	
Knowledge-intensive service	1,676	0.16	0.37	505	0.17	0.37	271	0.15	0.36	529	0.11	0.31	**

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Less knowledge-intensive service	1,676	0.03	0.17	505	0.02	0.15	271	0.03	0.17	529	0.02	0.14	
Countries (company location)												
JP	1,676	0.17	0.38	505	0.12	0.33	271	0.21	0.41	529	0.19	0.4	***
CN	1,676	0.06	0.24	505	0.03	0.18	271	0.06	0.23	529	0.03	0.17	
TW	1,676	0.04	0.21	505	0.03	0.16	271	0.05	0.21	529	0.04	0.2	
KR	1,676	0.03	0.18	505	0.02	0.12	271	0.03	0.18	529	0.03	0.17	
Rest of Asia	1,676	0.02	0.14	505	0.03	0.18	271	0.01	0.12	529	0.01	0.11	*
DE	1,676	0.06	0.24	505	0.07	0.25	271	0.07	0.25	529	0.08	0.27	
GB	1,676	0.05	0.22	505	0.07	0.26	271	0.04	0.2	529	0.06	0.24	
FR	1,676	0.04	0.19	505	0.05	0.22	271	0.03	0.17	529	0.05	0.21	
CH	1,676	0.03	0.17	505	0.06	0.23	271	0.01	0.12	529	0.03	0.17	***
NL	1,676	0.02	0.14	505	0.03	0.18	271	0.03	0.16	529	0.01	0.11	
Rest of Europe	1,676	0.09	0.28	505	0.12	0.33	271	0.06	0.24	529	0.09	0.29	**
US	1,676	0.34	0.47	505	0.33	0.47	271	0.35	0.48	529	0.35	0.48	
Rest of North America	1,676	0.01	0.11	505	0.02	0.13	271	0.02	0.15	529	0	0.06	**
Rest of the world	1,676	0.02	0.13	505	0.03	0.16	271	0.03	0.16	529	0.01	0.11	
No. of patent families	1,668	201 -31	793.8	505	121.18 (32.50)	297	271	98.42 (32.00)	187	529	455.80 (88.00)	1,337	***
Patents share in … over total number of company patents												
Electrical engineering	1,668	0.34	0.36	505	0.25	0.35	271	0.4	0.36	529	0.37	0.33	***
Instruments	1,668	0.14	0.2	505	0.16	0.24	271	0.13	0.17	529	0.15	0.17	***
Chemistry	1,668	0.26	0.34	505	0.31	0.36	271	0.2	0.29	529	0.22	0.29	***
Mechanical engineering	1,668	0.2	0.27	505	0.21	0.29	271	0.22	0.28	529	0.22	0.24	***
Other fields	1,668	0.06	0.15	505	0.07	0.17	271	0.06	0.14	529	0.04	0.1	***
Level of technological internationalization I (share of PF invented abroad over company's total patent number)	1,668	0.26	0.31	505	0.42	0.34	271	0.27	0.31	529	0.29	0.27	***

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Level of technological internationalization II (share of PF invented on the other continent over company's total PF number)	1,633	0.16	0.23	481	0.23	0.26	264	0.17	0.23	525	0.2	0.21	***
IP intensity (company's R&D expenditure (mean value over the period 2012-14; in EUR million) over its total PF number)	1,668	14.83 -2.84	66.78	505	10.36 (3.03)	21.6	271	12.67 (2.33)	40.5	529	6.78 (1.59)	39.63	***
Technological diversification	1,668	0.65	0.22	505	0.64	0.2	271	0.66	0.2	529	0.75	0.15	***

*Notes: N and SD refer to the number of observations and standard deviations, respectively. Reported are some median values in the parentheses. Kruskal Wallis test results on differences between company clusters: * p<0.10, ** p<0.05, *** p<0.01*

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